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PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Improvements in cable terminations.

We, ASSOCIATED ELECTRICAL INDUSTRIES LIMITED, a British Company having its registered office at 1 Stanhope Gate, London, W.1. (formerly of 33 Grosvenor Place, London, S.W.1.) do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

This invention is concerned with a method of, and means for, terminating a cable in such a manner as to relieve the electrical stress at and/or near the termination of the cable.

A single-core cable comprises an inner conductor or conductors surrounded by insulating material which is, in turn, surrounded by an outer electrically conductive screen. (The inner conductor or conductors are commonly surrounded by an inner electrically conductive screen which is surrounded by the said insulating material). In order to terminate such a cable, the outer conductive screen of the cable is removed, for a suitable distance from the end of the cable, and this removal causes the exposed insulating material and the end of the remaining outer conductive screen to tend to be subjected (when the cable is in use) to high electrical stresses which may cause electrical discharges to occur, tending to cause breakdown of the insulation of the cable.

In order to relieve such electrical stresses, it is known to build suitable structures (so-called "stress cones") upon the exterior of the insulating material of the cable. Considerable skill and time is necessary to build such structures correctly, to a shape which will properly relieve the said electrical stresses.

Evidence of the relief of the said electrical stresses is shown by an improvement in the electrical-discharge characteristics at the termination of the cable core in question. This electrical-discharge phenomenon may be detected in generally known manner by connecting suitable electrical testing equipment to the cable system incorporating the termination, and gradually increasing the test voltage until a suitable display (commonly upon a cathode-ray tube) reveals onset of the discharge. The voltage at which this occurs is commonly known as the discharge-inception voltage and, by the utilisation of suitably sensitive equipment and refined techniques, that discharge-inception voltage may be determined where the magnitude of the electrical discharge then appearing is as small as 1 pico-coulomb.

It is clear that improvement in electrical-discharge characteristics is shown by an increase in the discharge-inception voltage, the ideal working condition for the termination being when its discharge-inception voltage exceeds the voltage at which it is required to function.

For the purposes of this specification, the standard discharge-inception voltage is taken to be that voltage at which the magnitude of the electrical discharge does not exceed 1 pico-coulomb.

Other methods of relieving the electrical stresses are also known. In particular, it is known (e.g., as in U.K. patent specification No. 1,003,700) to bind the exposed insulating material and the end of the remaining outer conductive screen, with tape made of polyvinyl chloride (P.V.C.) which contains silicon carbide. With such an arrangement (see below), higher values of discharge-inception voltage are obtained than if no means of stress relief is employed. The arrangement has, however, certain disadvantages: in particular, considerable skill is again required, in that the tape must be wound on so as to lap correctly, attention being paid to

the mechanical tension of the tape. It is also believed that cyclic variations of temperature may cause the tape to become less effective, in relieving the electrical stress, than is desired.

Similar problems occur, in terminating a multi-core high-voltage cable. Such a cable may be regarded as formed by the juxtaposition of two or more cores each of the form of the single-core high-voltage cable described above, the two or more cores being surrounded by further material of an electrically conducting nature which may, in turn, be surrounded by a cable armour and/or a cable sheath. In this case, each of the cores must be terminated in such a manner as to relieve the electrical stresses at that termination.

According to one aspect of the invention, there is provided a method of terminating a single-core cable or at least one core of a multi-core cable, which method includes the steps of removing the said outer conductive screen, from the core in question, for a predetermined distance from the end of the cable and so as to expose the said insulating material of that core, and thereafter placing upon that core a pre-formed unitary sleeve made of elastic material containing silicon carbide, the sleeve being selected to have such a natural internal diameter, and being so placed, that it surrounds and clings closely around both a portion of the remaining end of the said outer conductive screen and also a next-adjacent portion of the said exposed insulating material, there remaining at the end of the core a portion of the said exposed insulating material which is not covered by the sleeve.

The advantages of this form of termination are that relatively little skill is required to place the sleeve in position, and that the operation is relatively quick.

Preferably, the elastic material of the sleeve is made from a natural and/or a synthetic rubber polymer.

The preferred rubber polymer is ethylene propylene rubber.

According to a second aspect of the invention there is provided a pre-formed unitary sleeve for use in a method according to the invention and made of elastic material containing silicon carbide.

The invention also includes a high-voltage cable terminated according to the method of the invention, or terminated with the aid of a sleeve according to the invention.

The invention may be put into practice in a number of ways, but one specific embodiment will now be described with reference to the accompanying drawings of which:

Figure 1 is a schematic longitudinal cross-section of a single-core high-voltage cable, and

Figure 2 is a graph illustrating the behaviour of one form of cable termination according to the invention.

Referring to Figure 1, the single-core high-voltage cable there shown has a single inner conductor 1 which is surrounded by insulating material 2 which is, in turn, surrounded by an outer electrically conductive screen 3. In order to terminate the cable (at the right-hand side in Figure1), the end of the inner conductor 1 is bared in known manner, as at 4. Further, the outer conductive screen 3 is additionally removed for a distance (L+M), so as to expose the outer surface of the insulating material for that distance. If the cable were then used the exposed insulating material and the end 5 of the remaining outer conductive screen would tend to be subjected to the high electrical stresses referred to above.

The basic proposal of the invention is to relieve these electrical stresses by placing upon the cable core a sleeve 6 made of elastic material containing silicon carbide, whereby the sleeve clings closely around the cable and surrounds a length K of the end 5 of the remaining outer conductive screen 3 and also surrounds a length L of the next-adjacent portion of the exposed insulating material. There remains, at the end of the cable, a length M of the exposed insulating material which is not covered by the sleeve 6, which length acts as a so-called "creepage length".

The elastic sleeve is chosen to have a natural internal diameter which is not greater than the outside diameter of the cable core with its outer conductive screen 3 removed, the intention being that the sleeve shall cling so closely around the cable that none or substantially none of the so-called "voids", i.e. air-filled spaces, shall occur between the sleeve 6 and that portion (L) of the exposed insulating material which is covered by the sleeve. In order to assist in the elimination of such voids, that latter portion of the exposed insulating material may be covered, before the sleeve 6 is placed in position, with a layer 7 of auxiliary insulating material which, when the sleeve is placed in position, is capable of flowing so as to tend to prevent the occurrence of such voids; we have found that a silicone gum may be employed for this.

The elastic material of the sleeve may be made from a natural and/or a synthetic rubber polymer, for example ethylene propylene rubber. In general, the elastic material may contain from 75 to 250 parts by weight of silicon carbide, per 100 parts by weight of the rubber polymer.

In general, the electrical resistance of such elastic sleeves is considerably changed when the sleeve is stretched; in general, it is therefore necessary, for a cable of given outside diameter, to employ a sleeve 6 having a corresponding internal diameter, whereby the sleeve will be stretched by a known and predetermined degree when it has been placed in position upon the cable.

If the sleeve 6 is required to have a more universal application, to a range of cables of different outside diameters, then the elastic material should also contain carbon black. Where a rubber polymer is used, the elastic material may thus also contain from 10 to 25 parts by weight of carbon black, per 100 parts by weight of the rubber polymer.

Where the sleeves were made from ethylene propylene rubber containing silicon carbide, it was found that a 10% stretching of the sleeves increased their electrical resistance by a factor of more than 20. This change of electrical resistance caused a considerable deterioration in the stress-relieving characteristics of such sleeves.

EXAMPLE

Sleeves and discs were manufactured, of the following composition:-

Material	Parts by Weight
Ethylene propylene rubber	100
Silicon carbide	200
Carbon black	20
Zinc oxide	5
"Flectol H"	0.5
Sulphur	0.4
"Perkadox Y 12/40"	10
Diphenyl guanidine	0.5

The ethylene propylene rubber was "Dutral N", sold by Shell Chemical Co. The silicon carbide was of an electrical grade, sold as "Metrosil 2730/320" by Associated Electrical Industries Limited. The carbon black was "Vulcan III", a high-abrasion furnace black sold by Cabot Carbon Co. The next four components are suitable agents for curing the rubber, "Flectol H" being an anti-oxidant sold by Monsanto Chemicals, and "Perkadox" being an organic-peroxide curing agent sold by Novadol Ltd. The diphenyl guanidine was included to counteract the slight acidity of the silicon carbide. ("Dutral", "Metrosil", "Vulcan", "Flectol" and "Perkadox are Registered Trade Marks).

The discs were moulded, and were 4 inches (10.16 cms) in diameter and had a thickness of 0.05 inches (0.127 cms); aluminium electrodes were evaporated on to the discs, and guard rings were applied. Measurements with a Twenty Million Megohmeter, using an external direct-current source, then showed that the electrical resistivity decreased from about 10^{12} ohm-cm at 1 Kilovolt per inch, to about 10^{01} ohm-cm at 5 Kilovolt per inch.

The sleeves were extruded at a temperature of about 100°C; they were then placed on a mandrel, wrapped in cloth, and cured for 30 minutes in steam at 150°C. (The sleeves may also be produced by the compression, transfer or injection types of moulding.)

When such a sleeve was stretched by 10%, it was found that its electrical resistance (at 2 Kilovolt per inch) increased from 0.8×10^{11} to 4×10^{11} ohms; when the sleeve was relaxed, the resistance decreased to 1×10^{11} ohms. These changes of resistance are considerably smaller than if the carbon black is omitted.

Before appying such a sleeve to the cable of Figure 1, the outer conductive screen 3 was first removed for a distance of (L+M) = 6 inches (15.24 cms). For higher voltage cables, (L+M) should be correspondingly larger. In some cases, the screen 3 may be easily removable; where the screen 3 is of the extruded type and is bonded to the insulating material 2, it may be removed by means of a rotary stripping tool which must be set to leave, in the insulating material 2, a spiral groove of the smallest practicable depth. (A groove depth of 0.004 inches, 0.01 cms, with a pitch of 0.1 inches, 0.254 cms, was found to be practicable.)

The silicone gum was then applied, in the form of a uniform thin layer 7 of length L′ somewhat greater than L. Typically, L=2 inches (5.08 cms), and L′= 2.5 inches (6.35 cms). The silicone gum may be "Silastoseal (Registered Trade Mark) B" sold by Midland Silicones Ltd., or "DP 276" sold by Imperial Chemical Industries Ltd.

Using a mechanical applicator, the sleeve 6, typically of length (K+L) = 3 inches (7.62) was then slipped on to the cable, such that the sleeve overlapped the outer screen 3 by a distance of K=1 inch (2.54 cms). The silicon gum flowed under the sleeve, some being expelled.

When "Silastoseal B" was employed, it was found to be preferable to leave the termination for 24 hours, to permit the gum to cure, before applying voltage to the cable. But where "DP 276" was employed, the voltage could be applied immediately.

In the case of a multi-core high-voltage cable, the same procedures are applicable to each of the cores of the cable, after the outer coverings of the cable have been removed (in known manner) so as to expose the cores.

In order to test the efficiency of the invention, various tests were made with two high-voltage cables of the triple-layer extruded-polythene type (i.e., the cables had an extruded inner screen surrounded by extruded insulating material, in turn surrounded by an extruded outer screen).

Cable A was a 6.3 kV (conductor-to-earth) cable having a diameter of 0.63 inches (1.6 cms), over the said insulating material (i.e., after removal of the said outer conductive screen) and had a standard inner conductor of cross-section 0.1 square inches (0.645 cm^2) surrounded by polythene of thickness 0.11 inches (0.279 cms). Cable B was an 8.7 kV (conductor-to-earth) cable having diameter of 0.9 inches (2.286 cms) over the said insulating material (i.e. after removal of the said outer conductive screen), and had a stranded inner conductor of cross-section 0.06 square inches (0.387 cm^2) surrounded by polythene of thickness 0.295 inches (0.749 cms).

The discharge-inception voltages (to give an electrical discharge not exceeding 1 pico-coulomb) were measured, for each of cables A and B, (a) with no stress-relief arrangements, (b) with stress relief by means of tape made of polyvinyl chloride containing silicon carbide, and (c) with stress relief by means of the ethylene-propylene rubber sleeves manufactured and applied in the manner just described. In case (c), the sleeves had a wall thickness of 0.05 inches (0.127 cms), and (Figure 1) K=1 inch (2.54 cms), L=2 inches (5.08 cms), and M=4 inches (10.16 cms); for cable A, the sleeve had a natural internal diameter of 0.62 inches (1.575 cms), and for cable B, the sleeve had a natural internal diameter of 0.85 inches (2.159 cms). The results are given in the following table:

TABLE

Type of Stress Relief	Discharge-inception voltage (kV r.m.s.) Cable A	Cable B
(a)	3.5 - 5	6.5 - 7
(b)	9 - 18	(not measured)
(c)	15 - 22	22 - 28

Using the sleeves of the invention, the discharge-inception voltage (V) is a function of the length L (Figure1). Figure 2 is a graph wherein (V), in kilovolts, is plotted as ordinate against L, in inches; curve A applies to the cable A and curve B to the cable B.

Where the sleeves contained carbon black, it was found that a sleeve of a given natural internal diameter could be satisfactorily applied to cables of different sizes. For example, an ethylene-propylene rubber sleeve of natural internal diameter 0.5 inches (1.27 cms) and containing both silicon carbide and carbon black was applied to a core of an 11 kV (between phase conductors, i.e. 6.35 kV conductors-to-earth) 3-core cable having polythene insulation, a circular conductor cross-section of 0.1 square inches (0.645 cm^2) and cores of diameter 0.7 inches (1.78 cm), and give a discharge-inception voltage of 15kV; a similar sleeve applied to a core of a 15 kV (between phase conductors, i.e. 8.7 kV conductors-to-earth) 3-core cable having a circular conductor cross-section of 0.06 square inches (0.387 cm^2) and cores of diameter 0.93 inches (2.36 cms) also gave a discharge-inception voltage of 15kV.

WHAT WE CLAIM IS:-

1. A method of terminating a single-core cable or at least one core of a multi-core cable, which method includes the steps of removing the outer conductive screen, from the core in question, for a predetermined distance from the end of the cable and so as to expose the insulating material of that core, and thereafter placing upon that core a pre-formed unitary sleeve made of elastic material containing silicon carbide, the sleeve being selected to have such a natural internal diameter, and being so placed, that it surrounds and clings closely around both a portion of the remaining end of the said outer conductive screen and also a next-adjacent portion of the said exposed insulating material, there remaining at the end of the core a portion of the said exposed insulating material which is not covered by the sleeve.

2. A method according to Claim 1, wherein the elastic material of the sleeve is made from a natural and/or a synthetic rubber polymer.

3. A method according to Claim 2, wherein the rubber polymer is ethylene propylene rubber.

4. A method according to Claim 2 or Claim 3, wherein the elastic material contains from 75 to 250 part by weight of silicon carbide, per 100 parts by weight of the rubber polymer.

5. A method according to Claim 4, wherein there are 200 parts by weight of silicon carbide.

6. A method according to any preceding Claim, wherein the elastic material also contains carbonblack.

7. A method according to Claim 6 together with any one of Claims 2-5, wherein the elastic material contains from 10 to 25 parts by weight of carbon black, per 100 parts by weight of the rubber polymer.

8. A method according to Claim 7, wherein there are 20 parts by weight of carbon black.

9. A method according to any preceding

Claim, wherein that portion of the said exposed insulating material which is surrounded by the sleeve is covered, before the sleeve is placed in position, with a layer of auxiliary insulating material which, when the sleeve is placed in position, is capable of flowing so as to prevent any air-filled spaces from occurring between the sleeve and that said portion of the said exposed insulating material.

10. A method according to Claim 9, wherein the auxiliary insulating material is a silicone gum.

11. A pre-formed unitary sleeve for use in a method according to Claim 1, the sleeve being made of elastic material containing silicon carbide.

12. A sleeve according to Claim 11, wherein the elastic material is made from a natural and/or a synthetic rubber polymer.

13. A sleeve according to Claim 12, wherein the rubber polymer is ethylene propylene rubber.

14. A sleeve according to Claim 12 or 13, wherein the elastic material contains from 75 to 250 parts by weight of silicon carbide, per 100 parts by weight of the rubber polymer.

15. A sleeve according to Claim 14, wherein there are 200 parts by weight of silicon carbide.

16. A sleeve according to any one of Claims 11-15, wherein the elastic material also contains carbon black.

17. A sleeve according to Claim 16 together with any one of Claims 12-15, wherein the elastic material contains from 10 to 25 parts by weight of carbon black, per 100 parts by weight of the rubber polymer.

18. A sleeve according to Claim 17, wherein there are 20 parts by weight of carbon black.

19. A method of terminating a cable, substantially as specifically described herein with reference to the accompanying drawings.

20. A sleeve, for use in terminating a single-core cable or at least one core of a multi-core cable, substantially as specifically described herein with reference to the accompanying drawings.

21. A cable terminated according to the method of any one of Claims 1-10 and 19.

22. A cable terminated with the aid of a sleeve according to any one of Claims 11-18 and 20.

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1,177,394 COMPLETE SPECIFICATION
1 SHEET
This drawing is a reproduction of the Original on a reduced scale.

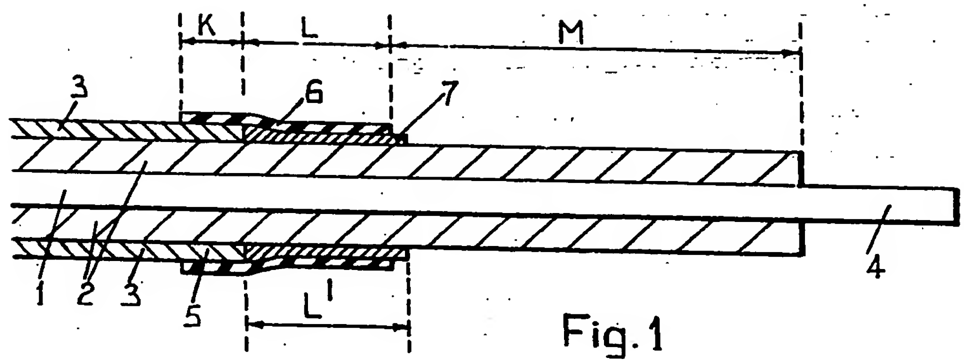

Fig. 1

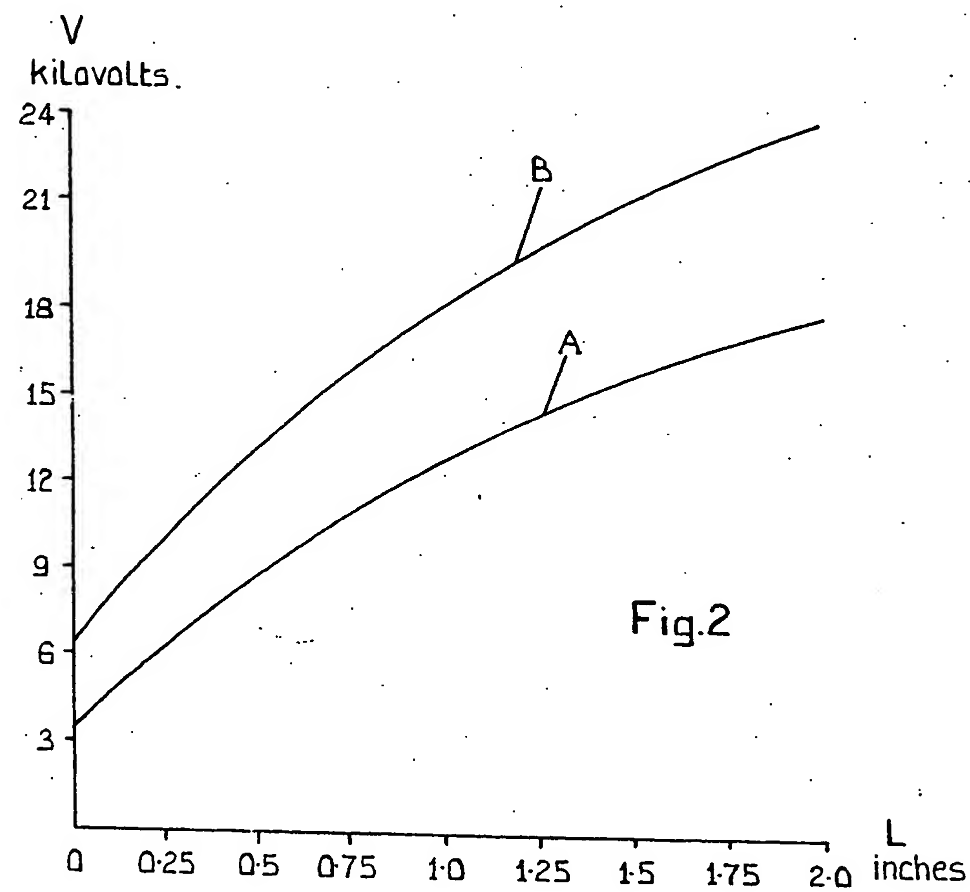

Fig. 2